Exploring a potential relationship between dual tasking and visual binding.

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Abstract

The purpose of this study was to understand if dual tasking and visual binding share a similar cognitive architecture. Here, it was hypothesised that the binding process would alleviate the executive demands associated with dual tasking, and consequently reduce the dual task cost (i.e., the reduction in task accuracy). Participants were asked to remember object and colour information concurrently. In the control condition, objects and colours were not related, but the "typical" condition used objects and colours that were found to be reliably associated, and would therefore be likely to reflect hardwired bindings in long term memory. There was no significant difference between the dual task cost for each condition, but some participants clearly benefited from the presence of associated colours and objects. Furthermore, this benefit was predicted by a participants' verbal span and vividness of visual imagery. However, it is unclear whether the benefit is attributable to associative priming or visual binding, impeding any implications for the relationship between dual tasking and visual binding. As such, future directions are discussed that could hopefully delineate the cause of the benefit in the typical dual task condition. In spite of this ambiguity, the data nonetheless revealed ways in which dual task cost can be reduced; this in turn carries implications for the production and use of efficient dual task strategies.

Introduction

Dual tasking and visual binding, like most cognitive processes, are studied separately. However, their recent impact in the neuropsychological literature has raised some telling parallels between them. The overarching assumption of this study is that these processes are somehow related, and could potentially reflect a shared form of processing in spite of their evident differences. In approaching this possibility, these processes could be potentially be revised in terms of a more general cognitive architecture which could in turn produce a different way of explaining these processes and their absence in disease.

The first section of the introduction is a description of these processes with reference to Baddeley's revised model of working memory (2000). This is to define and highlight the main difference between them. Specifically, dual tasking is argued to require additional executive effort and attentional resources whereas visual binding is depicted as an automatic process. The second section is a review of dual tasking and visual binding in ageing and disease. Here, the similar conclusions drawn from each set of literature are discussed along with the implications such conclusions have for the processes. Specifically, these similarities imply that dual tasking and visual binding use information in a conceptually similar way. The last section outlines hypotheses that can be used to test this implication, and is followed by a discussion of the experiment's methodology.

Dual tasking and executive control

Dual tasking is the process of performing two tasks simultaneously, such as remembering visual and verbal information at the same time, or cooking and having a conversation. The need for focus and attention is clear from our subjective experiences, and is also outlined in detail in neuropsychological literature. Here, dual tasking is thought to depend on an additional, executive function (Miyake *et al.,* 2000) that can allocate attentional resources to the tasks. Specifically, this function is thought to be carried out by the central executive of Baddeley's model of working memory (2000, see Figure 1). The central executive is based on Norman and Shallice's (1986) supervisory attentional system (SAS), and is an executive system dedicated to focusing, dividing and switching an individual's attention (Baddeley, 2002). In a dual task (e.g., remembering verbal and visual information concurrently), the central executive co-ordinates attention between verbal and visual code held in the phonological loop and visuospatial sketchpad, respectively.

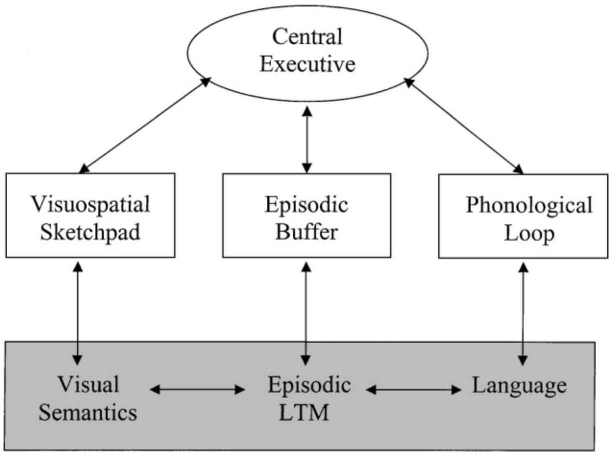

Figure 1: Baddeley's (2000) multi-component model of working memory. Areas in white represent fluid systems that exist in working memory, and areas in grey represent crystallised systems in long term memory.

The need for a central executive is highlighted by studies of DAT patients. Baddeley, Logie, Bressi, Della Sala and Spinnler (1986) observed that DAT patients who performed a primary visual tracking task and secondary verbal task demonstrated a significantly larger decrease in the secondary task than controls. Importantly, the authors noted that this dual task impairment was observed when both tasks were calibrated to the participants' maximum level of performance. Here, the tracking task and one of the verbal tasks (recalling a string of digits) were performed beforehand by the participants, and the highest level of performance that did not incur a significant amount of errors was taken as their maximum capacity. Therefore, all participants experienced the dual task under the same relative load; they were all performing at maximum capacity. By replicating of the deficit after calibrating the dual task, the authors interpreted the impairment as an inability to co-ordinate attention rather than finding the component tasks more difficult than controls.

Replications of these results through different dual tasks (Della Sala, Baddeley, Papagno & Spinnler, 1995) and manipulations of component task difficulty (Logie, Cocchini, Della Sala & Baddeley, 2004) are consistent with this interpretation of dual tasking. Evidence from neuroimaging also suggests dual tasking depends on executive resources. D'Esposito *et al*. (1995) observed dual task specific activation of the prefrontal cortex, but this finding has not been replicated. However, it is clear that a dual task scenario induces stronger (but not novel) activations for areas involved in the component task performance, including frontal areas presumed to underlie executive functioning (Adcock, Constable, Gore & Goldman-Rakic, 2000; Bunge *et al.,* 2000; Collette & Van der Linden, 2002). Overall, it is clear that dual tasking bears heavily on executive resources.

Similarly, dual tasking also depends on the amount of attention a person can give to the component tasks; this is distinct from the central executive impairment noted in DAT. Azouvi *et al.* (2004) observed that patients with a severe traumatic brain injury (TBI) demonstrated a dual task impairment when performing a random generation task and reaction time task concurrently. Although controls and TBI patients experienced longer latencies on a primary reaction time task in a dual task situation, the effect was significantly larger in patients. In spite of this deficit, patients were still able to divide and allocate attention strategically between tasks if they were instructed to do so. Although patients' overall performance was poorer than controls, the pattern of performance across different instructions for patients and controls was comparable. The authors concluded that the TBI patients' dual task impairments were "related to a reduction in available processing resources rather than an impairment of strategic processes responsible for attentional allocation and switching between tasks" (Azouvi *et al.,* 2004, p. 1266).

In sum, dual tasking requires significant cognitive effort; it demands executive resources and depends on sufficient attentional resources. In contrast, visual binding requires neither the central executive nor attention. It requires much less cognitive effort, and occurs automatically.

The automaticity of visual binding

Visual binding integrates visual information to form a single representation or unit (Brockmole & Franconeri, 2009). For instance, shape and colour information that is initially unrelated can be bound together to give a representation of a shape with that colour.

There is evidence to suggest that this process occurs automatically. For instance, Allen, Baddeley and Hitch (2006) employed dual task methodology to investigate the attentional demands of binding. Here, the degree to which a process is disrupted by an additional task indexes the amount of cognitive resources it usually requires. They observed that an additional task reduced memory for colours, objects and their bindings, but the reduction in memory for these features and bindings was comparable. This suggested that binding did not require more resources than those used in the retaining feature information in memory. Similarly, Gajewski and Brockmole (2006) demonstrated that participants were as likely to remember bindings as they were to remember single features after attention was diverted by invalid exogenous cues. Recently, Allen, Hitch and Baddeley (2009) demonstrated that the phenomena reported in Allen *et al.* (2006) persists for information presented cross modally (e.g., verbal colour information and visual shape information) and in the presence of demanding dual tasks. Furthermore, this binding occurs when the features are both separated across time and visual space (Karlsen, Allen, Baddeley & Hitch, 2010). These findings indicate that attention is not necessary for visual binding to occur, nor is it restricted to one modality or timeframe. It is therefore an automatic, implicit process. In these instances, bound information is presumed to exist in the episodic buffer of working memory (Baddeley, 2000). This component of the model (illustrated in Figure 1) is a passive, store of multimodal information. It can integrate information from the visuospatial sketchpad and the phonological loop, but can also receive episodic, multimodal information from long term memory. Information is retrieved from the buffer with the central executive and attention. This has been supported by evidence that memory for bindings is affected by the distraction of attention during recall (Brown & Brockmole, 2010). As such, whilst bindings can occur passively and implicitly, they are only consciously perceived through the use of attention (as posited by Allen *et al.* 2009).

However, whilst bindings are created automatically, their maintenance and availability varies with respect to what these bindings represent. Using terminology from VanRullen (2009), *hardwired* bindings reflect combinations of features that have been learned through exposure to real, natural objects. For instance, the shape of a leaf and the colour green are represented as a bound entity in long term memory as a result of repeatedly co-occurring. Conversely, *arbitrary* bindings reflect a new or meaningless combination of features, such as a blue circle, or red hexagon. Hardwired and arbitrary binding are also referred to as *conjunction detection* and *ad-hoc* binding, respectively (Hommel & Colzato, 2009).

The maintenance of arbitrary bindings depends on attention. Specifically, if bindings are formed and additional visual information is presented and attended to, individuals show poor memory for the original bindings. For instance, Allen *et al.* (2006) observed significantly poorer binding memory if bindings were presented across trials sequentially rather than simultaneously. Similarly, Logie, Brockmole and Vandenbroucke (2009) demonstrated that bindings were only retained across a series of trials if no interfering bindings were presented in between repeated trials. Lastly, Fougnie and Marois (2009) employed a dual task scenario to investigate the fragility of bindings. Here, participants completed a multiple object tracking (MOT) task after forming bindings. Here, participants followed target items move across a screen and were then asked to decide whether a probed item was a target. This caused a significant impairment for binding memory, but, interestingly, this effect was attenuated when the MOT task was stationary. This suggests that the bindings are more sensitive to interrupting bound visual information (i.e., object and motion information) than to single feature information (i.e., object information).

How can these findings be reconciled with Allen *et al.* (2006), who did not observe any effect of a dual task on binding memory? Critically, Allen *et al.* used distractor tasks that loaded on verbal – not visual - working memory. In doing so, they avoided introducing a bottleneck in visual processing, unlike the authors noted above. Hence, the maintenance of arbitrary bindings are jeopardised if additional information loads on visual attention, moreso if the imposing information is complex. This explains the apparently contrasting view presented by VanRullen (2009), who argued that arbitrary bindings could not be formed automatically. This claim was based on evidence that memory for arbitrary bindings can be impaired if attention is distracted by a secondary task (e.g., Fei-Fei *et al.,* 2005). However, in light of the evidence reviewed here, VanRullen's argument appears to conflate the production of arbitrary bindings with their maintenance and fragility.

Conversely, the tenacity of hardwired bindings is different to arbitrary bindings. Two lines of evidence support this statement. Firstly, the introduction of competing visual information – that is hazardous to arbitrary bindings – does not appear to affect bindings for natural objects. For instance, Reddy, Reddy and Koch (2006) observed participants' recognition memory for non-famous faces was equivalent for single (86%) and dual task (82%) situations, where the latter drew attention away from the faces and onto a letter discrimination task. Similarly, Fei-Fei, VanRullen, Koch and Perona (2005) found that this withdrawal of attention did not affect recognition memory for scenes, extending the evidence that the categorisation of natural scenes was also unaffected by a dual task (Li, VanRullen, Koch & Perona, 2002).

Secondly, the relationship between hardwired binding features appears to be stronger than those in arbitrary bindings. Colzato, Raffone and Hommel (2006) and Hommel and Colzato (2009) provided evidence for this using a priming paradigm. In this paradigm, participants viewed an object composed of two features (colour and shape), and were then presented with a test object that was either the same or different to the previous object. Participants indicated whether this object's shape was the same as the shape of the previous object. Crucially, the test object could differ in two ways: a completely different object had a different colour and shape to the initial object, but a partially different object only differed on one feature. Importantly, a test object with a repeated colour - but different shape - produces a delayed response. This is interpreted as the repeated colour eliciting the prior bound object's shape back into attention, which interferes with the current test information, subsequently delaying a participant's response. Importantly, Hommel and Colzato (2009) observed that this delaying effect was seen for both arbitrary (geometric shape and colour) and hardwired (shapes of fruit and their prototypical colour) bindings, but the effect was significantly larger for the latter. This suggests that the relationship between features in hardwired bindings is stronger than that of arbitrary bindings, as the relationship between arbitrary bindings takes less time to overcome.

In sum, hardwired bindings are more resilient than arbitrary bindings. With reference to Baddeley's (2000) model of working memory, this difference can be explained in terms of connections to long term memory. Specifically, arbitrary bindings do not have any connection to long term memory. As such, they are automatically created and left in the episodic buffer, which is a passive store. Without attention, they are likely to be overwritten. However, hardwired bindings are automatically created, but "backed up" by visual semantics and prior learning; they are therefore more resilient.

In summary, the following distinction between dual tasking and visual binding has been made: successful dual tasking depends on executive resources and attention, whereas visual bindings occur automatically. Furthermore, this implicit process of binding produces more resilient bindings if they reflect a learned association in long term memory. In spite of this distinction, a review of dual tasking and visual binding in ageing and disease indicates that the two processes may have a similar cognitive architecture.

The similarities between dual tasking and visual binding

Firstly, in spite of memory deficits associated with age, both processes are retained in ageing. Previously, dual tasking ability was though to deteriorate with age (e.g., Salthouse, Rogan & Prill, 1984). However, the negative effect of age is eliminated if the dual task is calibrated (as seen in Baddeley *et al.,* 1986). Studies that do so find no significant effect of age for dual tasking across verbal memory and visual tracking tasks (Della Sala, Foley, Beschin, Allerhand & Logie, 2010; Foley, Kaschel, Logie & Della Sala, 2011; Kaschel, Logie, Kazén & Della Sala, 2009) and also for verbal and visual memory tasks (MacPherson, Della Sala, Logie & Wilcock, 2007). An investigation from Logie, Della Sala, MacPherson and Cooper (2007) demonstrated that any effect of ageing on dual tasking is likely to result from a situation that places demands on working memory stores - that decrease with age (Bopp & Verhaegen, 2005) – rather than executive co-ordination processes or strategies. Similarly, Brockmole, Parra, Della Sala and Logie (2008) observed that binding does not deteriorate with age in spite of reduced visual working memory capacity. Elderly participants demonstrated a significantly poorer memory for shapes than younger participants (Experiment 2), but, importantly, did not show any difference in free recall of binding or feature information. Furthermore, there is no interaction between this difference and age, suggesting that elderly participants bind information to the same level as healthy young participants.

These findings are important for two reasons. Firstly, they demonstrate that these processes are spared in ageing in spite of poor component memory, and in doing so, highlight how these processes function. That is, they are both responsible for the simultaneous management of information, and potentially share a similar cognitive architecture (Figure 2). In the case of visual binding, different visual codes are brought together into a single, multimodal code in the episodic buffer. Attention is not necessary for this process. In the case of dual tasking, visual and verbal codes in their respective stores are handled simultaneously with the use of attention. That is to say, they are both responsible for the integration of separate streams of information to one point in time, and any effect of ageing appears to reflect the diminished memory for this information rather than an impairment of the processes *per se.*

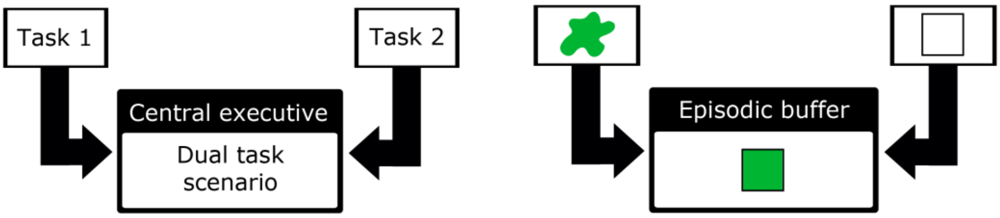

Figure 2: An interpretation of the cognitive architecture used in dual tasking and visual binding. Both processes combine simultaneous, but disparate, forms of information.

The possibility of a common cognitive architecture is supported by both processes' absence in DAT. The dual tasking impairment in DAT noted above deteriorates as the disease progresses (Baddeley, Bressi, Della Sala, Logie & Spinnler, 1991). In the case of visual binding, Parra *et al.* (2009b) observed that patients with DAT showed significantly lower binding memory for colours and objects than healthy elderly controls. Furthermore, this binding impairment was evident for preclinical patients of DAT (Parra *et al.,* 2010a). Specifically, carriers of the E280A single presenilin-1 mutation (a mutation that leads to autosomic dominant familial Alzheimer's disease in 100% of cases) evaded a diagnosis of DAT through neuropsychological assessment, but nonetheless showed a significantly poorer memory for bindings than controls, as did those who obtained a DAT diagnosis.

However, there are other processes that are also lost in DAT but retained in ageing. How can it be claimed that dual tasking and visual binding share a common architecture that is distinct from that of other impairments in DAT, such as significant episodic memory loss? Here, it is important to refer to impairment specificity. That is, dual task and visual binding deficits are specific to DAT, whereas episodic memory loss is not. This indicates that there is a specific pathology in DAT that causes impairment of both of these processes. Other, non-specific impairments may reflect a different pathology that is shared in other disorders. Both dual tasking and visual binding have, in their respective literatures, been identified as fundamental markers of DAT.

For instance, Parra, Abrahams, Logie and Della Sala (2010b) observed that the binding deficit in DAT is not seen in patients with depression. Similarly, and in the case of dual tasking, patients with depression are able to dual task, whereas those with DAT cannot (Kaschel *et al.,* 2009). Importantly, the authors observed this disparity after matching patient groups for episodic memory impairment (Experiment 2). Furthermore, patients with mild cognitive impairment (MCI) vary in dual task performance, causing no overall group impairment (unlike DAT, Foley *et al.,* 2011). Although MCI implies a conversion to dementia (Petersen, 2004), it is a contentious diagnostic category that incurs a rate of false positives (14.1 – 23.1%, Brooks, Iverson, Holdnack & Feldman, 2008). The heterogeneity of the impairment observed in Foley *et al.* (2011) has been hypothesised to reflect that some MCI patients will have a pathology that is indicative of progression to DAT - and therefore a dual task impairment - whereas others will not progress to DAT, and therefore show no dual task impairment. Lastly, although TBI patients can demonstrate a dual task impairment (Azouvi *et al.,* 2004), this is not a necessary consequence (Foley, Cantagallo, Della Sala & Logie, 2010).

In sum, the retention of dual tasking and visual binding in ageing and the specific deterioration of these processes in DAT suggest that these processes may depend on the same cognitive architecture to function. That is, they both combine simultaneous codes of information; this requires effort in dual tasking, but not in visual binding.

If these functions do depend on a similar cognitive architecture, then it stands to reason that the automaticity of binding can alleviate the executive cost of dual tasking. Specifically, if the simultaneous and different codes in a dual task can also be automatically bound into a single and stable entity, then there may be a reduced need for the executive resources usually required for dual tasking. This is because there will be no need to allocate or switch attention across stores, and the amount of information is effectively halved and stored in the episodic buffer. However, this effect will only be seen for hardwired bindings, as arbitrary bindings are easily overwritten.

A dual tasking and visual binding paradigm

The overall aim of this study was to test this prediction. Specifically, the major hypothesis is that the presence of hardwired bindings in a dual task should significantly alleviate the inevitable attentional demands of the dual task, and therefore improve dual task performance.

In order for hardwired binding to occur, the information in the dual task must be relevant to visual information and should exist in the individual's long term memory. The most intuitive solution is to use non-geometric objects and colours, since these co-occur to give stable semantic representations (Hocking & Price, 2008). Furthermore, this information can be presented cross-modally (as per Allen *et al.,* 2009), and will therefore avoid introducing a processing bottleneck in visual working memory. Specifically, colour information can be presented aurally, and object information can be presented visually.

How can colour and object information be presented to an individual in a dual task situation? The preloading paradigm used in MacPherson *et al.* (2007) is suitable for testing the primary hypothesis. First, a participant's is assessed for their maximum level of component task performance; the rest of the paradigm is calibrated to this level (or "span"). Participants perform two component tasks independently at span. In the dual task situation, these tasks are presented together. Here, participants encode information for the primary (or preloading) task. After this, they perform the secondary (or concurrent) task, and finally recall primary task information. A participant's performance in the dual task is compared to their performance when completing the tasks independently. This in turn can be used to calculate dual task cost. Specifically, cost represents the overall change in task proficiency or accuracy when two tasks are performed concurrently. Importantly, the cost is calculated with both single tasks in mind to capture any trade off that may exist (Della Sala *et al.,* 2010). This paradigm can therefore be used to assess a participant's ability to remember colours and objects, and infer what cost is associated when these tasks are performed concurrently. The critical observation is whether objects and colours in the dual task significantly reduce dual task cost compared to a control dual task condition.

The hypothesised process is as follows: after information in the preloading task and concurrent task is represented and held in working memory, the associated objects and colours should exist as stable bindings in the episodic buffer. As such, the individual's memory for both the colours and objects should benefit from the presence of a stable bindings. In contrast, if there is no association or long term representation for the binding of colours and objects, then their binding will occur automatically, but will not persist in the dual task situation due to a lack of "backing" from long term memory. This provides a useful control dual task condition.

Given that this paradigm assesses the interaction between working and long term memory, an additional aim was to explore if this beneficial effect was mediated by an individual's hardwired bindings in long term memory. Specifically, it was also hypothesised that participants with more vivid bindings, or better access to bindings, should demonstrate a greater reduction in dual task cost when hardwired binding was appropriate. Indirect evidence for this comes from Hulme, Maughan and Brown (1991), who demonstrated that participants had a greater capacity for verbal information that was drawn from long term memory (i.e., English words) than for information that had no long term representations (e.g., non-words or words from a foreign language). As such, the present study was designed to also assess participants' vividness, availability and semantic richness of visual bindings in long term memory.

Before approaching these hypotheses, it was noted that there is no normative data for common colour-object associations, and therefore it was not clear what colours and objects may exist as hardwired bindings in long term memory. Although Hocking and Price (2008) reported objects that had a prototypical colour and those that did not, there was no justification or evidence for these associations. Rather than make such assumptions *a priori*, a pilot study was conducted to investigate which objects have a prototypical colour.

Assessing colour-object associations

Method

Participants. 20 undergraduate students from the University of Edinburgh participated in this study, and received academic credit for participating.

Materials and Apparatus. 515 black and white pictures of common objects were taken from the International Picture Naming Project (IPNP: Bates *et al.,* 2000). For each object, the IPNP includes normative data representing the mean reaction time to produce its predominant name, the number of responses where its predominant name is given, and the number of alternative names that have been assigned to it. A list of 11 common colours was created and is given in the Appendix. *E-Studio* was used to create the computer program that presented the colours and objects and collected participant's responses. *E-Run* was used to run the experiment on a personal computer.

Procedure and Design. Participants were read instructions before the experiment began. Participants viewed each of the objects with the list of colours. For each object, they were asked to select a colour that they felt was associated with the object. If the participant felt that no colour was associated with the object, they were asked to select a "no typical" response. Participants responded by clicking on the colour with the mouse, and then saw the next object. The experiment continued in this way until the participant responded to the last object. All participants viewed the same list of colours and saw the same objects, once, in the same order. The experiment was approved by the University of Edinburgh Psychology Research Ethics Committee.

Results

Frequencies of colour assignment were viewed for each object. An instance where an object had a single colour associated with it for ≥ 80% of the total responses was defined as a typical colour-object association. This gave 121 objects with a colour that was typically associated to them ("typical objects"), and 394 objects that did not have a typical colour ("control objects"). For instance, a ghost constituted as a typical object, as 80% or more of the participants associated it with the colour white. Conversely, a pirate constituted as a control object, as no one colour was consistently assigned to it.

The pilot experiment produced a set of materials that could be defined as having a reliable association between them, which could in turn be used in a dual task situation where hardwired binding was applicable.

Method

Participants

48 students from the University of Edinburgh participated in this study and earned £6 per hour for participating.

Procedure and Design

Participants gave consent and heard an overview of the whole procedure from the experimenter. At the start of a new task, the experimenter gave brief instructions to the participant, who then read instructions given on screen. The tasks began when the participant was prepared and informed. To begin, participants completed memory tasks in the following order: immediate colour span, immediate object span, delayed colour span, delayed object span, colour single task, object single task, and the dual task. These tasks are described below and their general procedures are illustrated in Figures 3-5.

Colour span. Participants heard colours spoken in a list through headphones for (number of colours * 1) seconds. When the list finished, participants had to repeat all the colours in the order they had heard them back to the experimenter. A participant passed if they correctly recalled all colours in the correct order. The next list was presented after participants gave their response. Participant initially heard three lists containing two colours. If they correctly recalled at least two out of three lists, they heard three more lists containing three colours. The test iterated in this way until participants either failed to correctly recall at least two lists of colours or reached the upper boundary of ten colours in a list. The maximum number of colours at which they could correctly recall at least two of the three lists in order was taken as their colour span. Immediate span tasks did not contain a delay between presentation and testing. Delayed span tasks contained a delay of (immediate object span * 2) seconds.

Object span. Participants saw objects presented on a computer monitor for (number of objects * 1) seconds. After the presentation, a test array appeared which contained the objects presented before and an equal number of distracter items. Participants had to click on the objects they had seen before. Participants passed if they correctly clicked all the target objects. The next array was presented after participants gave their response. The iteration conditions, calculation of span and timings of immediate and delayed conditions were the same as described in the colour span task.

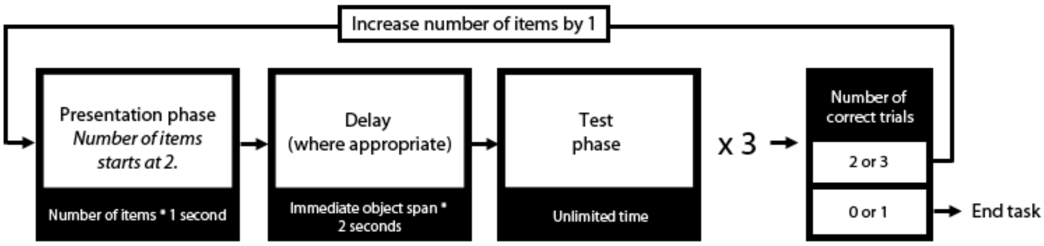

Figure 3: The general span test procedure.

Single tasks. This test was designed to assess a participant's immediate and delayed memory for a set number of colours or objects. In each instance, their immediate object span defined the number of items they had to remember. Like span trials, items were presented for (number of items * 1) seconds. Objects and colours were presented as they were in the span task. In the test phase, participants had (number of items * 1) seconds to recall the items. Object memory was tested as it was in the span task. Colour memory was assessed differently; the number of correctly called colours was recorded, and participants could recall these in any order.

Trials with no delay between item presentation and recall were used to assess immediate memory. Trials with a delay of (immediate object span * 2) seconds between item presentation and recall were used to assess delayed memory.

Figure 4: The single task procedure.

Test for dual task performance. To start, participants observed a set of items. This was the start of the preload task. The participant's immediate object span defined the number of items, and participants observed the items for (number of items * 1) seconds. Immediately after this, participants observed a second set of items. This was the start of the interpolated task. The number of items and presentation duration were the same as those for the preload task. Immediately after this presentation, participants recalled the interpolated task items in under (number of items * 1) seconds. Lastly, and immediately after this, participants recalled preload task items in under (number of items * 1). The presentation and assessment for colours and objects were the same as the single task.

“Typical” dual tasks used typical objects and their associated colours. There were two types of control dual tasks. Type 1 presented control objects with random colours. Type 2 presented typical objects with colours that were not typically assigned to them.

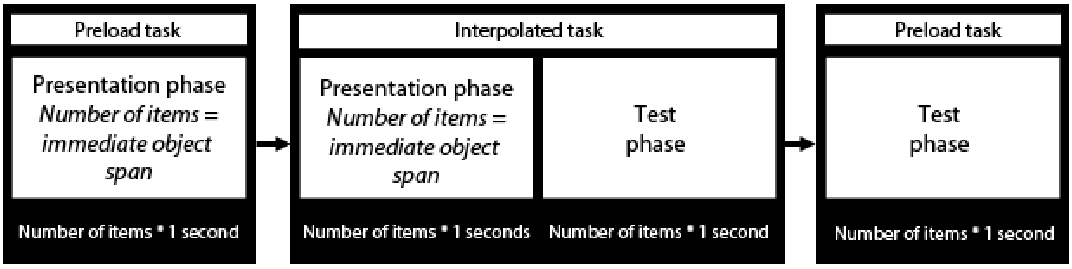

Figure 5: The dual task procedure.

After these tasks were performed, participants completed four questionnaires. These were the Spontaneous Use of Imagery Scale (SUIS, Reisberg, Pearson & Kosslyn, 2003), Vividness of Visual Imagery Questionnaire (VVIQ, Marks, 1973), scale of semantic strength (SSS; Parra, Spelling, Kuske, Della Sala & Logie, in preparation) and a debriefing questionnaire. Copies of these questionnaires can be found in the Appendix. The debriefing questionnaire was always administered immediately after the dual task.

The procedure took roughly 50 minutes to complete, but the duration varied with respect to the participant’s immediate object span; it defined the duration of the delayed span, single and dual tasks.

Participants completed colour single task trials as two blocks of four trials; one block of immediate trials, and one of delayed trials. The immediate block always occurred first. Participants completed 16 object single task trials as four blocks of four trials; two blocks of typical objects, and two of control objects. For each of these two blocks, one contained immediate trials, and the other contained delayed trials, and the immediate block always occurred first. The dual tasks were presented in two parts, where each part contained two blocks of two trials. One part contained the typical materials, and the other contained control materials. In each part, one block contained two trials where the colours constituted as the preload task information and the other block used objects for the preload task. Within the control part, each block contained one Type 1 trial and one Type 2 trial.

A within-participants design was used. The order of typical and control conditions and trials was counterbalanced across every two participants to negate any potential practice effects for object single and dual tasks. Additionally, the order of dual task information was counterbalanced across participants. The experiment was approved by the University of Edinburgh Psychology Research Ethics Committee.

Materials and Apparatus

E-Studio was used to create a computer program that presented all relevant memory tests in one session. *E-Run* was used to run the computer program on a personal computer, and standard headphones were used to hear the colour names. Participants made responses to objects with the mouse. The questionnaires were in paper form.

The stimuli used in the memory tests were the same objects and colours used in the pilot study. To avoid any effect of object frequency in object recognition, control and typical objects presented in the experiment (either as targets or distracters) were chosen to have comparable naming frequencies (Table 1).

Table 1: Mean Object Nameability Across Typical and Control Single and Dual Tasks.

	Single Task		Dual Task	
	Typical	*Control*	*Typical*	*Control*
Target Object	84	86	90	85
Distracter Objects	82	83	89	89

Results and Analysis

The analysis employed both quantitative and qualitative approaches to participants' dual task performance. The first three sections detail the quantitative analysis. First, measurements of single and dual task accuracy were analysed across all experimental permeations. Next, the variable of dual cost was calculated and analysed across all conditions of the dual task. Finally, by adopting an individual differences approach, the beneficial effect of a typical dual task condition was analysed using multivariate regression, using participants' spans and questionnaire scores as predictor variables.

The remaining sections detail the qualitative analysis of participants' approach to the dual task. The first section is a discussion of the specific comments participants had about their perception of the dual task and any strategies they may have used. The final section demonstrates which broad characteristics define participants who did or did not benefit from the presence of hardwired bindings.

Single and dual task accuracy

The dependent variables of task accuracy were calculated as the mean percentage of colours and objects correctly remembered in typical and control dual and single task[1] situations. This produced eight (2 x 2 x 2) accuracy variables for each participant.

Two two-way within-participants ANOVAs were conducted to test the effects of condition (typical or control) and feature (object or colour) on accuracy in single and dual tasks.

The first ANOVA revealed that there was no significant effect of condition or feature on single task accuracy. No significant interaction was found. The second ANOVA revealed that there was a significant effect of feature on dual task accuracy (F (1, 47) = 17.563, $p <$ 0.001; η^2 = 0.272), but there was no significant effect of condition. No significant interaction was found. This demonstrated that participants had significantly greater accuracy for colours, but did not differ in accuracy across the typical and control conditions. This is represented in Figure 6.

[1] Preliminary analysis showed that the order of dual task information (i.e., colour-to-object vs. object-to-colour) did not reveal any significant difference in dual task accuracy. As such, the delayed and immediate single tasks are collapsed to give an average single task score.

Dual task cost

The independent variable of dual task cost was calculated from measures of accuracy using this equation, adapted from Della Sala *et al.* (2010):

$$\text{Cost of dual task} = 100 * \left(\frac{\text{Single task accuracy} - \text{Dual task accuracy}}{\text{Single task accuracy}} \right)$$

This produced four (condition x feature) cost variables for each participant. A two-way within-participant ANOVA revealed an effect of feature on dual task cost (F (1, 47) = 7.7365, $p < 0.01$; $\eta^2 = 0.141$), but there was no significant effect of condition. This demonstrated that participants showed significantly lower cost for colours and no difference in cost across typical and control conditions. This is represented in Figure 7.

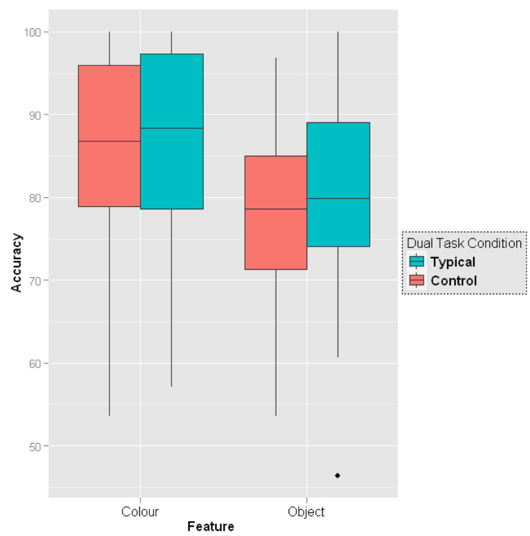

Figure 6: Rates of average object and colour accuracy across control (red) and typical (blue) dual task conditions.

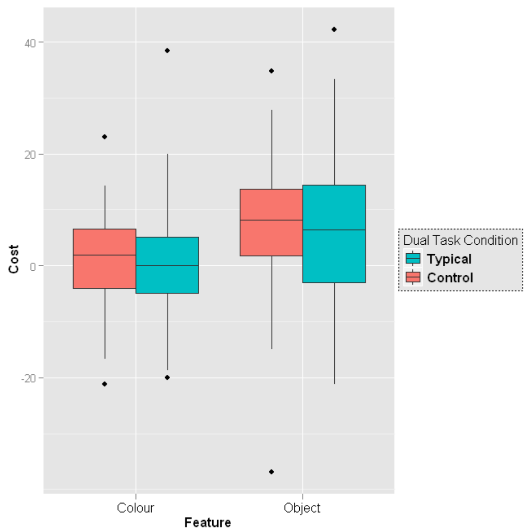

Figure 7: Dual task costs for object and colour memory across control (red) and typical (blue) dual task conditions

In sum, there was no significant difference between dual task cost and accuracy when objects and colours were related and when they were not. However, as noted in the secondary set of hypotheses, the degree to which these associations are used or available may vary according to the individual's long term memory.

Individual Differences

A new variable was created to investigate the potential individual differences in the benefit drawn from the presence of hardwired bindings. This variable was calculated as the difference in cost a participant experienced in the control and typical dual task situations:

(Average control condition cost) – (Average typical condition cost)

This variable is referred to as a participant's "association benefit". A positive value indicated that a participant experienced a smaller dual task cost when an association existed between the objects and colours. Figure 8 illustrates that this variable is centred on zero and approximates a normal frequency distribution. An individual differences analysis with multiple regression models was conducted to investigate the causes of this variance. Here, participants' spans and questionnaire responses are used as predictor variables. These are given in Table 2.

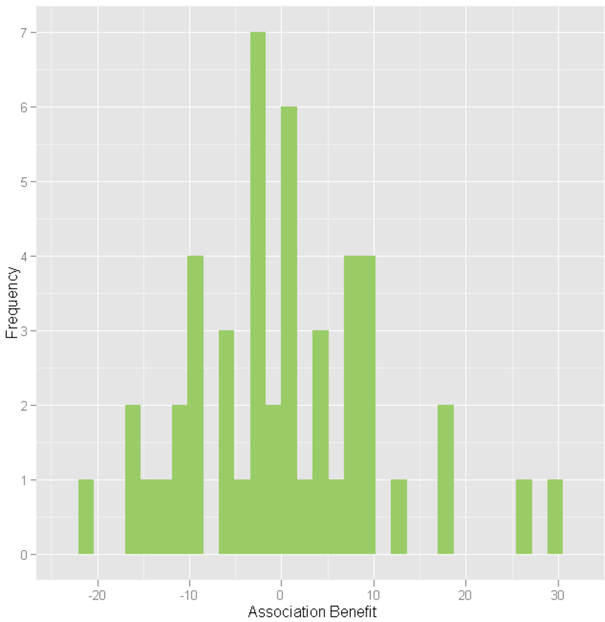

Figure 8: The distribution of association benefit scores across participants. A positive value indicates lower dual task cost in the typical association.

Table 2: Descriptive statistics of participants' average spans and questionnaire scores

	Mean (SD)	Range
Spans		
Colour		
Immediate	5.25 (0.83)	3 – 7
Delayed	5.38 (0.91)	3 – 7
Object		
Immediate	6.52 (1.17)	4 – 9
Delayed	7.56 (1.24)	4 – 9
Questionnaires		
SUIS	40.42 (6.19)	23 – 54
VVIQ	62.19 (9.36)	34 – 79
SS	44.31 (8.66)	21 – 58

The best fitting linear model of association benefit demonstrated a significant effect of average colour span (β = -5.1725, standard error = 1.7512, $p < 0.01$) and scores on the VVIQ (β = 0.3098, standard error = 0.1452, $p < 0.05$). Whilst an interaction effect was observed at borderline significance, its inclusion did not significantly improve model fit. This suggests the effects are additive. No significant effects of accuracy, average object span or other questionnaire measures were seen, and their inclusion in the final model did not improve fit. The best fitting model explained 19% (Adjusted R^2 = 0.19) of the variance in association benefit. Correlation analysis demonstrated that the effect of colour span is significantly negative (r = -0.38, $p < 0.01$), and the effect of visual vividness is positive (r = 0.27, p = 0.6). This implies that participants with lower colour spans and/or higher scores of visual vividness experience a lower cost in the typical dual task condition than in the control dual task condition. In sum, the benefit received from the association of colours and objects varies according to an individual's colour span and visual vividness.

Quantitative analysis explained which participants were likely to benefit from a typical dual task situation. However, it could not indicate whether these participants detected or exploited the association between colours and objects. An investigation of participants' responses in the debriefing questionnaires demonstrated how they approached the dual task scenario and whether they used or noticed the associations between colours and objects. Similarly, because participants were divided on whether they showed an association benefit or not (see Figure 8), the final part of the qualitative analysis was to understand whether there were any group-level characteristics that defined participants who do (and do not) experience an association benefit.

For the purposes of the following analysis, the participants' responses to the debriefing questionnaire were investigated to determine a) what strategies the participants had used throughout the experiment and b) whether they had noticed any connection between the colours and objects.

Individual approaches to the dual task

Of the 48 participants that completed the experiment, only three reported any connection between objects and colours in the dual task (P1, P11, P37). Of these three, only one demonstrated a reduced cost in the typical dual task relative to the control dual task (P37).

Across the dual task conditions, only five participants considered explicitly associating colours and objects together as a strategy (P30, P37, P38, P47, P48). However, only one noted that this was a beneficial strategy (P37). This participant also demonstrated a smaller cost in the typical dual task situation. All other participants commented that a focus on the associations would impair memory for the colours and objects themselves. It should also be noted that these participants were the only participants who explicitly stated any potential cross-task strategy; the remainder of the participants were more concerned with focusing on the two tasks individually. Furthermore, no participants stated that they would attempt a better dual task strategy if they had to repeat the task again.

In sum, noticing the association between colours and objects does not entail an association benefit. Similarly, the presence of an association benefit usually occurs without the participant explicitly associating the colours and objects, which in turn is seen as a costly, attention-demanding strategy. Lastly, the evidence that most participants approached and commented on the dual task as two component tasks suggests that they were less likely to relate preload and concurrent task information together.

Group analysis

Participants who scored an association benefit greater than zero were placed in the "benefit" group; the smaller typical dual task cost suggests they benefited from the presence of associated colours and objects. All other participants were placed in the "no benefit" group, as they experienced a cost in the typical condition that was equal to or larger than the cost in the control condition. This suggests that the presence of associated objects and colours did not improve their dual task performance. This group classification placed exactly half (n = 24) of the participants in the benefit group, and the other half in the no benefit group. Importantly, this division did not reflect the order in which dual task conditions were completed (e.g., typical condition first), and is therefore not due to a practice effect.

There was no significant difference between the groups' average object span, colour span, VVIQ, SUIS or SS scores. As such, the different frequency of strategies was investigated for each group.

These responses were given freely, and then categorised into strategies as follows: a) association, where colours or objects are semantically grouped together (e.g., objects that are animals, primary colours, etc.); b) chunking, where grouping objects or colours with no semantic basis (e.g., the first three colours in a list, objects presented close together); c) rehearsal, which involves repetition of colour and object names; d) visualisation, which is a colours only strategy where participants imagine the colours on a spectrum or wheel; e) story, which is an object only strategy, where participants generate an *ad-hoc* sequence to tie all objects together into a single string of information (e.g., "the hippopotamus sat on the chair, eating a cherry…"); f) combinations, which entails the use of multiple strategies; g) and no strategy.

The frequencies of these strategies across the groups are represented in Figures 9 and 10. Most noticeably, the benefit group demonstrated rehearsal as a strategy for colour memory more often than the no benefit group and also more often than other strategies. Conversely, the no benefit group appears to use combinations of strategies to remember colours more than the benefit group. The most noticeable difference in object strategies used by both groups is that only no benefit participants use chunking to help remember objects. The distribution of colour strategies in the benefit group was the only distribution that was significantly different from the normal distribution (χ^2 (5) = 17.5, p < 0.01). This indicates that the use of rehearsal as a strategy is a significant characteristic of the participants in the benefit group.

In sum, participants who demonstrate an association benefit were also those who reported using rehearsal to remember colours.

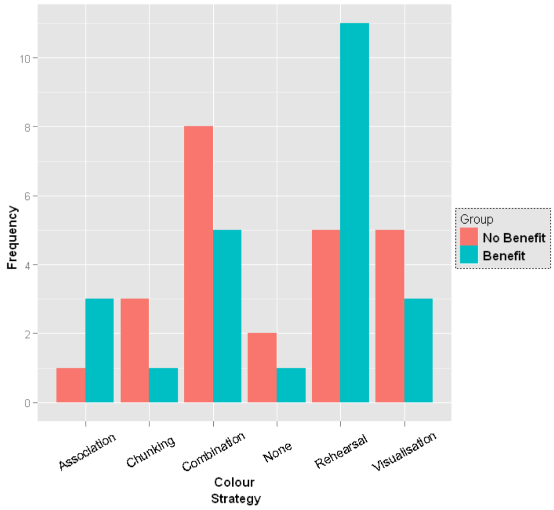

Figure 9: The distribution of strategies used by the benefit group (blue) and the no benefit group (red) when remembering colours.

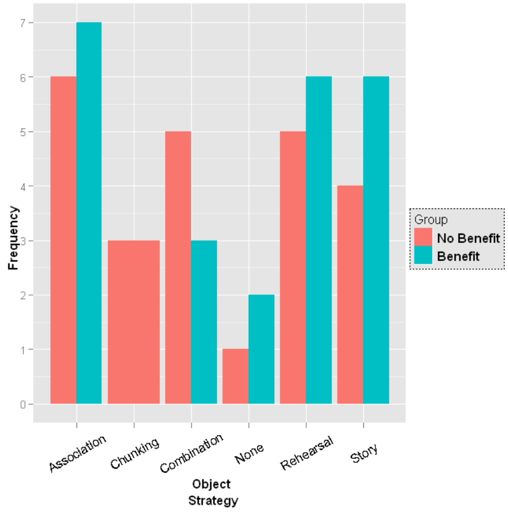

Figure 10: The distribution of strategies used by the benefit group (blue) and the no benefit group (red) when remembering objects.

Discussion

The main aim of this study was to investigate a potential relationship between dual tasking and visual binding. Here, the primary hypothesis was that a dual task that involved colours and objects that exist as hardwired bindings would significantly alleviate the executive demands required to dual task. In turn, this reduced need for executive demands would make the dual task easier, and therefore introduce a smaller dual task cost. Given that this manipulation involved the use of representations stored in long term memory, a secondary, open hypothesis was that the effect would vary according to an individual's access to and quality of such colour and object bindings in long term memory.

There was no significant difference in dual task accuracy or cost between the typical and control dual task condition. Whilst this would appear to counter the primary hypothesis, the difference in cost between these conditions, labelled the association benefit, varied across participants (Figure 8). This suggested that some – but not all - participants showed better dual task performance in a condition where objects and colours were associated. This variance presumably prevented the overall difference in cost between the dual task conditions from reaching statistical significance. Importantly, this difference in association benefit is not an artefact of counterbalancing; if all participants who scored a positive association benefit also completed the typical dual task last, it would be clear that the association benefit would simply reflect a practice effect. An individual differences analysis outlined some causes of this variance, and revealed that the association benefit was significantly predicted by a participant's VVIQ score and average colour (verbal) span, suggesting that its variance does not reflect a chance distribution. In sum, the analysis revealed that dual task cost can be reduced when colours and objects existed as bindings in long term memory, but this effect was sensitive to individual differences, including the individual's long term memory representations. As such, both of the experimental hypotheses are partially supported.

Visual binding and dual tasking

The central question for this discussion is: what does the association benefit represent? The experimental hypotheses were designed to demonstrate a relationship between dual tasking and visual binding. As such, it is imperative to understand if the association benefit truly reflects the binding process. Unfortunately, it is ambiguous what process caused the reduction in cost. Specifically, the association benefit seen here can be interpreted in two ways.

The first interpretation is that the difference in cost is due to the successful integration of information. Here, associated colours and objects are bound and held in the episodic buffer. As such, the amount of information is effectively halved, therefore improving performance in contrast to the control dual task; technically, participants are performing a task at less than span level, since they are retaining a smaller number of items in working memory. The second interpretation is that the difference in cost is due to the increased availability of information through priming. Here, the change in dual task cost is due to the increased activation of one set of information as another set is attended to. As such, the process of retrieval is facilitated, as is commonly seen in priming studies of related lexical items (e.g., Neely, 1977). These interpretations implicate different areas of the brain and cognitive systems. As reviewed by Parra *et al.* (2009b), learned associations imply the medial temporal lobes and hippocampus, whereas binding reflects an interaction of disparate cortical areas and can occur without the hippocampus (Baddeley, Allen & Hitch, 2011).

Therefore, if the association benefit is driven by binding in short term memory, then the study's assumption of a shared cognitive architecture between dual tasking and visual binding is valid. However, this claim cannot be made if the effect is simply due to associative priming, as this reflects spreading activation rather than binding in working memory. As such, it is critical that the cause of the association benefit is correctly understood before any strong conclusions regarding visual binding and dual tasking are made. Unfortunately, the data do not help delineate the nature of the association benefit.

Firstly, responses taken from the debriefing questionnaire imply that the association benefit could reflect both processes. On one hand, the majority of participants who demonstrated an association benefit did so without explicitly noting any association between colours or objects or exploiting said association to improve dual task performance. This in turn implies that binding did not drive these participants' association benefit, because retrieval of information from the episodic buffer is theorised to depend on conscious awareness. However, the response of one participant indicated that they noticed and consciously exploited the colour-object associations to help improve dual task performance. Accordingly, they demonstrated an association benefit. This suggests that they may have used hardwired bindings in the episodic buffer to aid dual task performance, but the insight to this participant's process is only as deep as their questionnaire response, and consequently cannot be argued that this strictly reflects binding.

Secondly, individual differences analysis of the association benefit suggests that it represents a binding process. Specifically, the positive effect of VVIQ on association benefit implies that the reduction of cost in the typical dual task situation depends on the participant's ability to bind visual information, as the recall of complex imagery and episodes is dependent on access to multimodal information held and produced in the episodic buffer (see Baddeley, 2000). Furthermore, the evidence that SUIS scores did not significantly predict changes in the association benefit demonstrates that the reduction in cost is not dependent on the ease at which complex imagery comes to mind; this argues against the priming interpretation of the association benefit.

In sum, the data present an unclear interpretation of what the association benefit represents. At this point, it is clear that, whilst the benefit has been observed with the current paradigm, strong implications regarding the shared architecture of dual tasking and visual binding cannot be made at this time. However, the ambiguity that restricts progress here can be resolved with further research. Specifically, the same paradigm used here can be modified to identify what process causes the association benefit to occur.

The first modification would be to introduce different levels of dual task difficulty, as indexed by the number of items in a dual task above or below an individual's span. If the effect observed here is due to the binding of information, then participants who demonstrate an association benefit should demonstrate a comparable benefit for typical dual tasks that present items at up to twice their span level. However, if association is the main cause of the benefit, then there should be a linear relationship between difficulty and association benefit. Here, whilst participants' responses would be facilitated, they will still be performing above span level, and demonstrate greater task cost as a result.

The second modification would measure the latencies of participant's responses. If participants' recall for items is faster in the typical condition in contrast to a control dual task, this could arguably reflect the facilitating effect caused by associative priming. Furthermore, the effect may also be accompanied by scores on the SUIS; its lack of an effect here is presumably because this study's observations were based on the end state of the process (i.e., accuracy) rather than the speed at which this process was carried out.

In summary, further research using a modified version of this study's paradigm will explain whether the association benefit is due to integration through binding in working memory, or strengthened activation through priming and associative long term memory, or both. If binding is the cause for reduced dual task cost, it can be argued that these processes share a similar cognitive architecture, and implications regarding the specific pathology in DAT can be discussed at that time.

So far the data have been discussed with respect to the experimental aims and the broader theoretical issue of dual tasking and visual binding's relationship. Nonetheless, analysis of the data yielded some important, but unexpected effects that can reduce dual task cost. Specifically, participants who have low span and use rehearsal in the typical dual task condition in a dual task cost tended to show lower dual task cost. Furthermore, participants demonstrated lower dual task cost for tasks that used colours in contrast to objects. Since these effects are unexpected - and therefore given post hoc explanations - they cannot be used to explain the nature of association benefit, and cannot be used to confirm or disprove the assumed relationship between dual tasking and visual binding. However, these findings merit some discussion, as they introduce possible ways to reduce dual task cost, and can potentially aid dual task performance or rehabilitation (e.g., Schwenk, Zieschang, Oster & Hauer, 2010). Accordingly, the effects that have reduced dual task cost are now discussed here to better understand why this may have occurred, and to understand whether these effects can form the basis of efficient dual task strategies.

Reducing dual task cost

Without understanding the exact cause of the association benefit, the data suggest that dual task performance can be improved if the component tasks contain associations that are held in long term memory. Essentially, this finding mirrors previous evidence that memory for verbal information is improved when said information matches representations in long term memory (Hulme, Maughan & Brown, 1991). However, the effect's sensitivity to individual differences in this study implies that simply using associated information in a dual task will not necessarily reduce cost. Overall, though, the significant predictor of VVIQ scores on a participants' association benefit indicates that the strategy may be appropriate if the necessary long term representations are intact.

The negative relationship between span and dual task cost in the typical condition can be interpreted in two ways. The first interpretation presupposes that participants with high spans approach the dual task in a different way to low span participants. Here, participants with a high colour span may be more likely to verbalise information in working memory. As such colours and objects are likely to be stored in the phonological loop (as seen in Parra, Della Sala, Logie & Abrahams, 2009a) and not distributed across both stores (see Figure 1). As such, the participant is likely to introduce a processing bottleneck (Duncan, Martens & Ward, 1997) and dual task performance as a whole decreases as component tasks are processed serially. By implication, participants with a low verbal span are less likely to burden the phonological loop, and divide visual and verbal information across the stores accordingly. In doing so, low span participants can avoid the bottleneck and keep both forms of information in working memory, allowing the association benefit to take place.
The second interpretation is based on a study of proactive interference (PI, Kane & Engle, 2000). Here, participants were asked to remember and recall four different lists of items. High span participants were able to avoid interfering information presented in other lists. By contrast, participants with low verbal spans were more likely to incorrectly recall information from the other list. However, this difference between groups was removed when attention was distracted; high span participants demonstrated a larger PI effect, but the effect did not change for low span participants. Participants with higher span were theorised to have access to more executive resources that could be used to separate information effectively; low span participants were thought to lack these resources. Furthermore, Osaka, Nishizaki, Komori and Osaka (2002) argue that, in cases of PI, participants with low span are specifically impaired in their ability to inhibit information they have previously focused on. For the present study, it could be argued that low span participants could not dedicate resources to help segregate colours and objects they have attended to, which could ostensibly increase the chance of the association benefit occurring through binding or associative priming. It is important to note that this posited effect is distinct from simply being able to cross tasks together; if this were the case, low span participants would simply be better at dual tasking with no specific preference to the typical condition.

At present, it is neither possible to conclude which of the two interpretations is more appropriate, nor to state if they are mutually exclusive. However, these interpretations lead to testable predictions. If this effect of span on association benefit reflects a bottleneck, then participants who demonstrate an association benefit should no longer show the benefit if they are made to verbalise all items in the dual task. In the case that the effect of span represents interference, then participants who demonstrate an association benefit should also be likely to make more source errors in recognition tests for items in the component tasks.

The evidence those who benefited from typical colour-object associations used rehearsal as a strategy for colour tasks may be a reflection of the low span participants in the group. That is, participants with low span appear to benefit from rehearsal strategies more than high span individuals (Turley-Ames & Whitfield, 2003). As such, the evidence that rehearsal is a “trademark” of participants who show an association benefit may in fact reflect low span participants who adopted rehearsal as a strategy and maintained it when it was found to be effective. It is therefore unclear if the effect of rehearsal is spurious, but can nonetheless be tested. If the use of rehearsal is a significant cause of reducing cost in a typical dual task situation, then all participants would presumably demonstrate an association benefit if they were instructed to use rehearsal as their only strategy. If this were the case, the implications of such an effect could be discussed at that time.

Lastly, the significantly lower dual task cost for colours, at face value, appears to demonstrate that dual tasking with verbal information is easier. However, the effect outlined in the analysis may be an artefact of experimental design. Specifically, participants at the dual task stage may have become aware of the colours used, as only 11 colours were used throughout the procedure, whereas 515 different objects were used. As such, memory for colours in the dual task may be aided by a practice or familiarity effect. Alternatively, it is possible that participants found the object recognition harder than the colour recall; the former required fast movements with the mouse. This potential confound could be resolved using a simple yes/no recognition test, where test objects are presented serially and only after a response is given. As such, the feature effect is most likely to reflect an artefact of method, and is unlikely to have a significant implication for dual tasking.

In summary, the effect of condition – as mediated by span and long term memory representations – on dual task cost can be explored further to understand whether dual task cost can be reduced through particular strategies and approached. However, it may be that these strategies are not applicable to all individuals.

Conclusions

This study applied a new dual task paradigm to understand whether dual task performance can be improved by using information that could be bound in working memory. Although dual task performance could be improved by using colour-object associations, this effect – the association benefit – is more sensitive to individual differences than predicted and unclear in nature. As such, these findings alone cannot refute or confirm the larger question and assumption that visual binding and dual tasking share a cognitive architecture. In spite of this ambiguity, the presence of the association benefit, and the conditions under which it can occur, raise important theoretical considerations regarding where and when dual task costs can be reduced.

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Appendix

Colour list
Red, Blue, Green, Yellow, Purple, Pink, Brown, Orange, Gray, White, Black

Debriefing Questionnaire

What strategy did you use?
1. Did you use only one strategy throughout? If more, explain.
2. Did you notice any connection between stimuli (e.g., colours and objects)? If so, explain.
3. Did you find any task easier than other tasks? If so, explain.
4. Did you find any sets of stimuli more difficult to remember than other? If so, explain.
5. If you had to perform this task again, would you do it differently? If so, explain.
6. Do you have any other comments or views on the task?

Spontaneous Use of Imagery Questionnaire (SUIS; Reisberg, Pearson & Kosslyn, 2003)

Please read each of the following descriptions and indicate the degree to which each is appropriate for you. Do not spend a lot of time thinking about each one, but respond based on your thoughts about how you do or do not perform each activity. If a description is always-completely appropriate, please choose “5”; if it is never appropriate, choose “1”; if it is appropriate about half of the time, choose “3”; and use the other numbers accordingly.

1	When going to a new place, I prefer directions that include detailed descriptions of landmarks (such as the size, shape and colour of a gas station) in addition to their names	1 2 3 4 5
2	If I catch a glance of a car that is partially hidden behind bushes, I automatically "complete it", seeing the entire car in my mind's eye.	1 2 3 4 5
3	If I am looking for new furniture in a store, I always visualise what the furniture would look like in particular places in my home.	1 2 3 4 5
4	I prefer to read novels that lead me easily to visualise where the characters are and what they are doing instead of novels that are difficult to visualise.	1 2 3 4 5
5	When I think about visiting a relative, I almost always have a clear mental picture of him or her.	1 2 3 4 5
6	When relatively easy technical material is described clearly in a text, I find illustrations distracting because they interfere with my ability to visualize the material.	1 2 3 4 5
7	If someone were to tell me two-digit numbers to add (e.g. 24 and 31), I would visualize them in order to add them.	1 2 3 4 5
8	Before I get dressed to go out, I first visualize what I will look like if I wear different combinations of clothes.	1 2 3 4 5
9	When I think about a series of errands I must do, I visualise the stores I will visit.	1 2 3 4 5
10	When I first hear a friend's voice, a visual image of him or her almost always springs to mind.	1 2 3 4 5
11	When I hear a radio announcer or DJ I've never actually seen, I usually find myself picturing what they might look like.	1 2 3 4 5
12	If I saw a car accident, I would visualize what had happened when later trying to recall the details.	1 2 3 4 5

Total Score _______

Visual Vividness of Imagery Questionnaire (VVIQ; Marks, 1973)

1. For items 1-4, think of some relative or friend whom you frequently see (but who is not with you at present) and consider carefully the picture that comes before your mind's eye.

1. The exact contour of face, head, shoulders and body.
Choose one of the following answers
   5. Perfectly clear and lively as real as seeing
   4. Clear and lively
   3. Moderately clear and lively
   2. Dim and vague; flat
   1. No image at all, you only "know" that you are thinking of the person

2. Characteristic poses of head, attitudes of body, etc.
Choose one of the following answers
   5. Perfectly clear and lively as real as seeing
   4. Clear and lively
   3. Moderately clear and lively
   2. Dim and vague; flat
   1. No image at all, you only "know" that you are thinking of the person

3. The precise carriage, length of step, etc., in walking.
Choose one of the following answers
   5. Perfectly clear and lively as real as seeing
   4. Clear and lively
   3. Moderately clear and lively
   2. Dim and vague; flat
   1. No image at all, you only "know" that you are thinking of the person

4. The different colours worn in some familiar clothes.
Choose one of the following answers
   5. Perfectly clear and lively as real as seeing
   4. Clear and lively
   3. Moderately clear and lively
   2. Dim and vague; flat
   1. No image at all, you only "know" that you are thinking of the person

2. Visualize a rising sun. Consider carefully the picture that comes before your mind's eye.

5. The sun is rising above the horizon into a hazy sky.
Choose one of the following answers
   5. Perfectly clear and lively as real as seeing
   4. Clear and lively
   3. Moderately clear and lively
   2. Dim and vague; flat
   1. No image at all, you only "know" that you are thinking of the scene

6. The sky clears and surrounds the sun with blueness.
Choose one of the following answers
   5. Perfectly clear and lively as real as seeing
   4. Clear and lively
   3. Moderately clear and lively

2. Dim and vague; flat
1. No image at all, you only "know" that you are thinking of the scene

7. Clouds. A storm blows up, with flashes of lightning.
Choose one of the following answers
5. Perfectly clear and lively as real as seeing
4. Clear and lively
3. Moderately clear and lively
2. Dim and vague; flat
1. No image at all, you only "know" that you are thinking of the scene

8. A rainbow appears.
Choose one of the following answers
5. Perfectly clear and lively as real as seeing
4. Clear and lively
3. Moderately clear and lively
2. Dim and vague; flat
1. No image at all, you only "know" that you are thinking of the scene

3. Think of the front of a shop which you often go to. Consider the picture that comes before your mind's eye.

9. The overall appearance of the shop from the opposite side of the road.
Choose one of the following answers
5. Perfectly clear and lively as real as seeing
4. Clear and lively
3. Moderately clear and lively
2. Dim and vague; flat
1. No image at all, you only "know" that you are thinking of the scene

10. A window display including colours, shapes and details of individual items for sale.
Choose one of the following answers
5. Perfectly clear and lively as real as seeing
4. Clear and lively
3. Moderately clear and lively
2. Dim and vague; flat
1. No image at all, you only "know" that you are thinking of the scene

11. You are near the entrance. The colour, shape and details of the door.
Choose one of the following answers
5. Perfectly clear and lively as real as seeing
4. Clear and lively
3. Moderately clear and lively
2. Dim and vague; flat
1. No image at all, you only "know" that you are thinking of the scene

12. You enter the shop and go to the counter. The counter assistant serves you. Money changes hands.
Choose one of the following answers
5. Perfectly clear and lively as real as seeing
4. Clear and lively
3. Moderately clear and lively
2. Dim and vague; flat
1. No image at all, you only "know" that you are thinking of the scene

4. Finally, think of a country scene which involves trees, mountains and a lake. Consider the picture that comes before your mind's eye.

13. The contours of the landscape.
Choose one of the following answers
5. Perfectly clear and lively as real as seeing
4. Clear and lively
3. Moderately clear and lively
2. Dim and vague; flat
1. No image at all, you only "know" that you are thinking of the scene

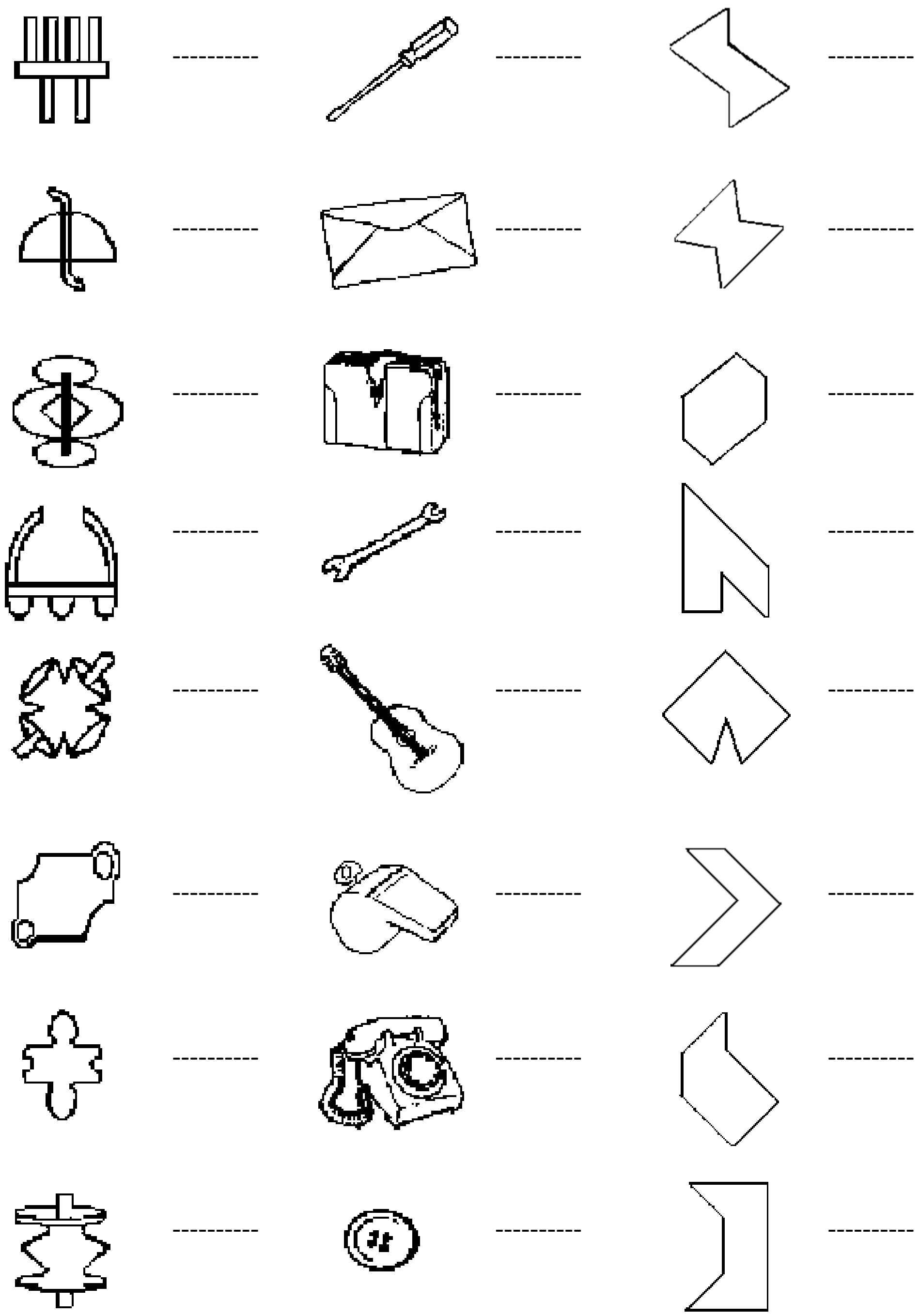
14. The colour and shape of the trees.
Choose one of the following answers
5. Perfectly clear and lively as real as seeing
4. Clear and lively
3. Moderately clear and lively
2. Dim and vague; flat
1. No image at all, you only "know" that you are thinking of the scene

15. The colour and shape of the lake.
Choose one of the following answers
5. Perfectly clear and lively as real as seeing
4. Clear and lively
3. Moderately clear and lively
2. Dim and vague; flat
1. No image at all, you only "know" that you are thinking of the scene

16. A Strong wind blows on the trees and on the lake causing waves.
Choose one of the following answers
5. Perfectly clear and lively as real as seeing
4. Clear and lively
3. Moderately clear and lively
2. Dim and vague; flat
1. No image at all, you only "know" that you are thinking of the scene

Scale of Semantic Strength (SSS; Parra, Spilling, Kuske, Della Sala & Logie, unsubmitted)

Please write beside each figure the name you think best describe each of them. If you can not find any name, leave the space blank.



Calculating SSS

Participants' responses were compared against mode responses for the items in the questionnaires. The number of matching/agreeing responses was divided by the number of items to give a percentage that acted as the participant's semantic strength.